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On-Road Measurments of Transit Bus Emissions

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Introduction

- The EPA has set increasingly stringent emissions standards on Heavy-Duty Vehicles in recent years.
- Emissions tests in-lab have been used by manufacturers to check compliance with EPA regulations, but these tests have differed from results found on-road.[1]
- Pierce Transit was one of the first transit fleets in the US to have 100% CNG buses. They advertise these as "lean, green, 'clean machines'".[2]
- King County Metro, operator of 250 hybrid buses, claims: "Hybrid-electric buses are good for the region's air quality".[3]

Questions

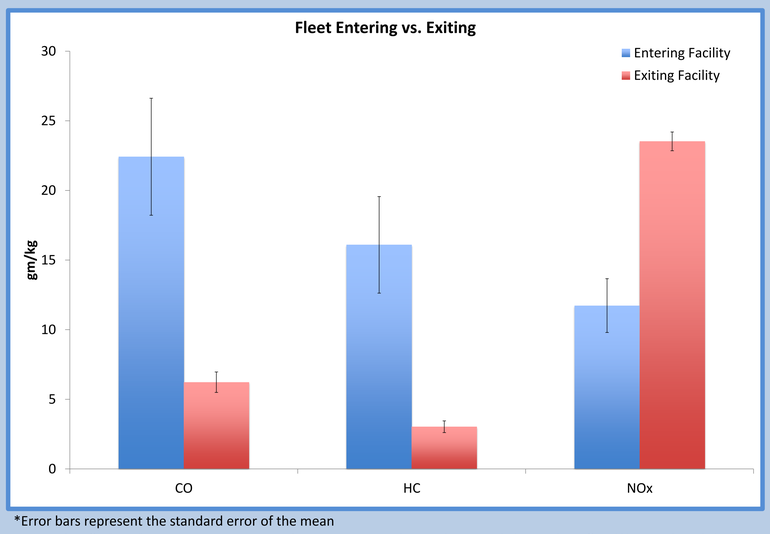
- Are the new engine technologies, that come with new EPA standards, improving the emissions? Do the improvements come with side effects?
- Are the tests in the controlled laboratory indicative of their use on road?
- Do the emissions measured on-road meet the EPA standards?

Experimental

- All buses were measured using the FEAT remote sensing device. The FEAT uses ultraviolet, visual, and infrared spectroscopy to measure carbon monoxide (CO), hydrocarbons (HC), nitric oxide (NO), nitrogen dioxide (NO_2 and collectively with NO known as NO_x), and ammonia (NH_3) emissions.
- All buses measured were operated by King County Metro, Pierce Transit, and Sound Transit.
- 770 valid measurements were taken from June 6th – June 17th, 2011 at the Federal Way Transit Center:

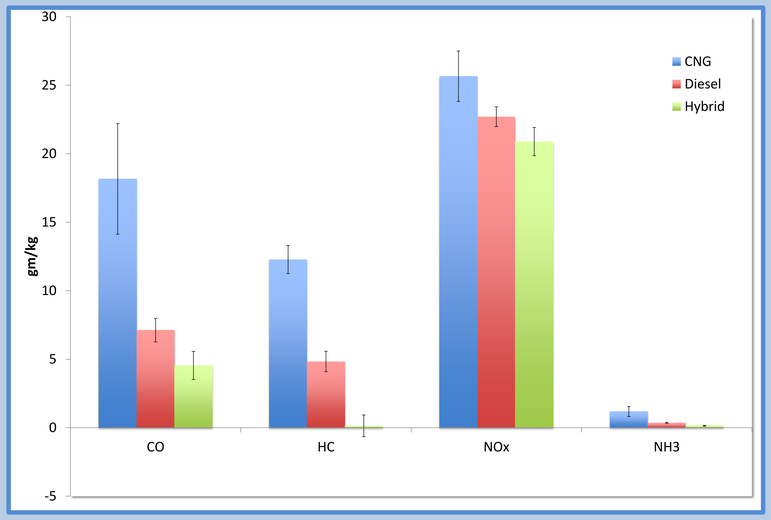
Direction	CNG	Diesel	Hybrid
Entering Facility	5	24	40
Exiting Facility	95	384	222

Results

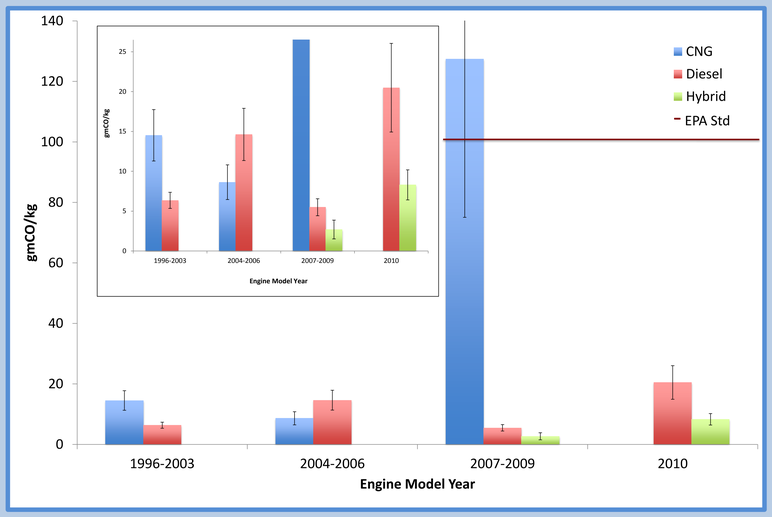


*Error bars represent the standard error of the mean

- 91% of the buses measured were accelerating exiting the facility. The higher hit-rate of exiting buses arises from a larger exhaust plume at acceleration than at idle, which was typical of buses entering the facility. Buses with less than 0.3% CO_2 measured are invalidated.
- CO and HC emissions were higher when buses were coming into the station.
- NO_x emissions were higher while buses were accelerating out of the station. This is the expected result of diesel engines under load.[4]

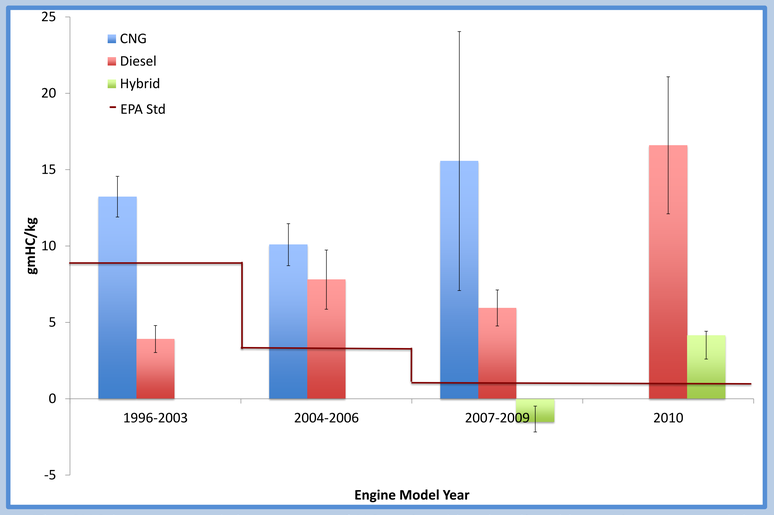


- CNG buses emitted more CO, HC, NO_x, and NH_3 than the other fuel types.
- Hybrid buses had the lowest emissions.
- Significant NH_3 slips were not found in diesel or hybrid type buses, but were found in CNG type buses.
- The increase in NH_3 found in CNG buses is caused by the Three Way Catalyst (TWC) in CNG buses that attempts to eliminate excess CO, HC, and NOx emissions.

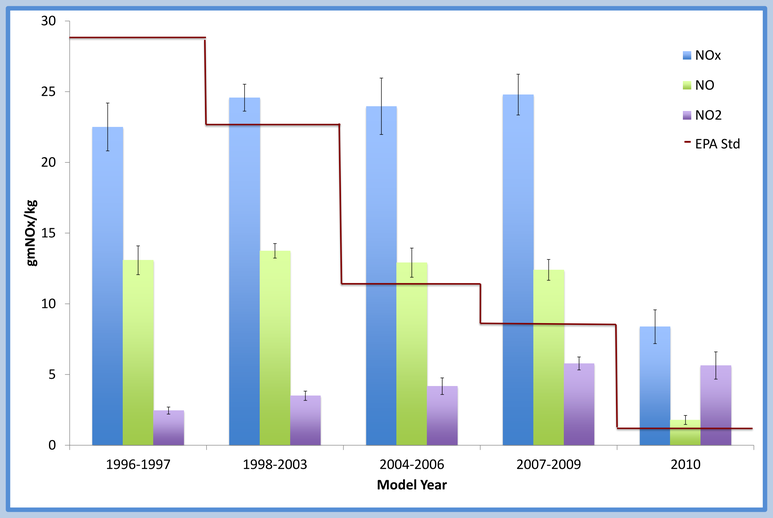


*EPA values are estimated. EPA standards are given in g/bhp⍰hr. The conversion factor of 0.15 kg fuel/bhp⍰hr gives the g/kg units shown.

- The CO emissions of 2010 model year buses were higher than previous group years.
- 2007-2009 CNG buses had a very large amount of CO, 96% higher than the amount of CO a 2007-2009 diesel emits (all exiting).
- Every engine model year range we measured met the EPA standard for CO except for 2007-2009 CNG buses.



- The CNG buses exceed the amount of HC emitted by the diesel buses in every model year group that contained CNG buses. This is most likely because CNG buses emit a large amount of methane hydrocarbons, whereas diesels predominantly emit non-methane hydrocarbons (NMHC).
- The EPA standard only includes NMHCs, but the FEAT measures all HC types.



- Total NO_x output was above set EPA maximums starting with the 2004-2006 standards
- Total NO_x output did not change from 1996-2009, but it significantly decreased in the 2010 model year

Conclusion

- The 2010 bus technology has decreased the NO_x emissions, but has increased the CO and HC emissions when compared with previous years.
- A side effect of these improved technologies seems to be the large increase of CO emissions found in the 2007-2009 CNG buses. The CO, which is normally well below, has surpassed the EPA standards.
- A surprise was that no NH_3 slip was found in the 2010 model year buses. However, this side effect was found in CNG buses and probably caused by their TWC.
- The tests performed in lab must meet EPA standards for the bus to be legally sold. The results on road differ from EPA standards. The CO emissions were generally much less than the standard, while the HC and NO_x emissions were generally above.

References

[1]Burgard *et* al. On-Road, In-Use Gaseous Emission Measurements by Remote Sensing of School Buses Equipped with Diesel Oxidation Catalysts and Diesel Particulate Filters.
[2]http://www.piercetransit.org/cng.htm
[3]http://metro.kingcounty.gov
[4]Heywood, *Internal Combustion Engine Fundamentals;* McGraw-Hill: New York, 1988.

Acknowledgements

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